Epitaxial Growth of AlN on Si(111) by Laser MBE

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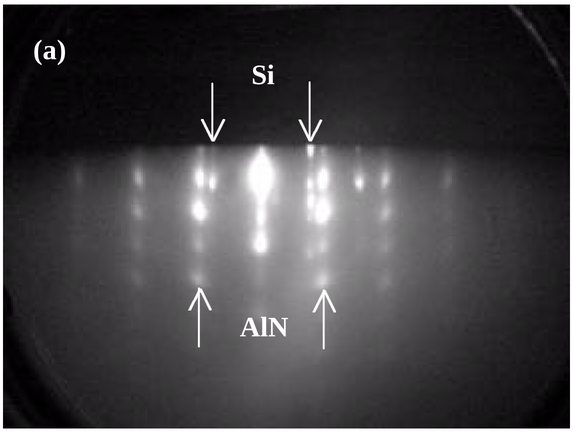
Epitaxial growths of group III-nitride semiconductors have attracted much attention because of their outstanding optical properties. Various substrates for the epitaxial growths have been studied, which include Al_2O_3, SiC, and Si. Among these materials, use of Si wafers is the most attractive because it enables us to integrate GaN optical devices with Si LSIs[1]. Si wafers, however, have been less popular than Al_2O_3 as epitaxial substrates for group III-nitrides due to the poor crystalline quality. This problem can be at least partially attributed to the nitriding reaction of the Si surfaces just before the epitaxial growths. It is difficult to avoid this nitriding reaction because the conventional epitaxial techniques for the growth of Group III-nitrides utilize highly active nitrogen sources such as NH_3 or N_2 plasma. To solve this problem, we have applied laser MBE[2],[3] for the epitaxial growth of group III-nitride semiconductors on Si. Since laser MBE does not use active nitrogen sources, we can expect reduction in nitriding reaction with Si surfaces. In this presentation, we will talk about the early stage of the epitaxial growths of AlN by laser MBE on Si(111), which are investigated with XPS, RHEED, and AFM.

We have grown the AlN on Si(111) with a KrF excimer laser MBE apparatus. After the Si(111) substrates were cleaned by piranha solution, they were dipped into 5% HF solution to remove the native oxide layer on the Si surface. Then, the Si(111) substrates were introduced into the laser MBE growth chamber. The laser light (λ=248nm, τ=20ns) ablated an AlN target (99.9% purity) with an energy density of 3 J/cm^2 and a pulse repetition rate of 10 Hz. The background pressure of the growth chamber was 3×10^{-9} torr. During the film growths, N_2 gas was introduced up to 1×10^{-5} torr by the flow of N_2 (99.9999%purity) into the chamber through a variable leak valve. The AlN films were deposited at a substrate temperature of 800 ºC. The surface during the growths was in-situ monitored with RHEED. To investigate the quality of the hetero-interface between AlN films and Si (111) substrates, we have characterized the surfaces at the early stage of the epitaxial growth using the XPS apparatus, which is connected to the laser MBE chamber in vacuum. AFM and XPS measurements were performed for various AlN film thicknesses.

The RHEED pattern from the Si (111) substrate just before the growth of AlN was sharp streak. After the AlN growth with a nominal thickness of 6Å, the RHEED patterns of Si substrates were weakened and the background intensity increased, which indicates that a distorted AlN layer grew homogeneously. At the nominal film thickness over 12Å, the RHEED pattern changed into clear spotty pattern which includes diffraction spots from both Si and AlN as shown in Fig.1(a). This indicates that agglomeration of AlN took place due to the stress buildup caused by the increase of the film thickness. Figure 1(b) shows the AFM image of the AlN film at this stage. One can clearly see the existence of AlN nuclei. Further increase in the growth thickness of AlN reduced the intensity of the diffraction spots from the Si substrate and the spots disappeared at a nominal AlN thickness of 80Å. This phenomenon indicates that a large portion of the AlN is incorporated in the nuclei and the two-dimensional AlN layer grows slowly. Careful RHEED observations revealed that the epitaxial relationship between AlN and Si is (0001)AlN//(111)Si with in-plane alignment of [11-20]AlN//[1-10]Si.



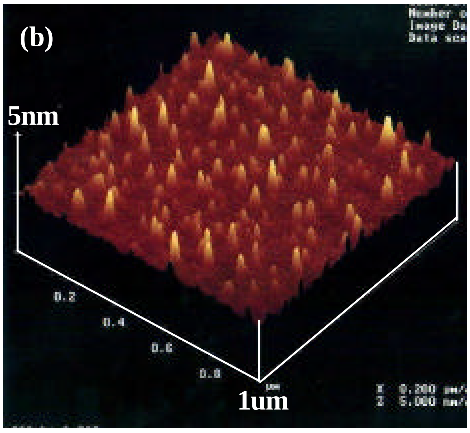


Fig. 1 (a) RHEED pattern of the AlN film grown on Si(111) substrate at 800°C with the electron beam parallel to [11-20] AlN.
(b) 1×1um AFM image.

We also investigated the hetero-interface between AlN films and Si (111) substrates using XPS. The photoelectron spectra for Si*2p* were measured for the nominal AlN thickness ranging from 6Å to 280Å. Figure 2 shows the normalized intensities of Si*2p* as a function of nominal AlN film thickness. A theoretical attenuation line on the assumption of two-dimensional growth without diffusion are also shown in this figure. Note that the experimental attenuation line for Si*2p* is clearly bent at a nominal AlN film thickness of 12Å. This coincides with the thickness where the AlN agglomeration occurred.

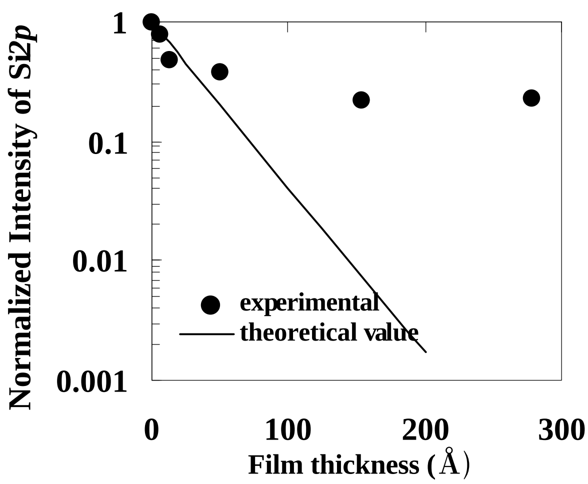


Fig. 2 Normalized Si*2p* intensities as a function of nominal AlN film thickness.

In conclusion, we have investigated the early stage of the AlN epitaxial growth on Si (111) by laser MBE with RHEED, AFM, and XPS. RHEED and AFM observations revealed that initial growth of AlN proceeds two-dimensionally and the agglomeration of AlN occurs at a nominal AlN thickness of 12Å. The attenuation of Si*2p* XPS peak intensity is consistent with RHEED and AFM observations.

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